Development of a Natural Gas-to-Hydrogen Fueling System

DOE Hydrogen & Fuel Cell Merit Review

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Hydrogen Fueling Systems

Problem Statement/Challenges

- Overall Problem Statement
  - Making hydrogen competitive with gasoline ($/kg or $/vehicle mile traveled)
- Challenges
  - Flexible & efficient fuel processors
  - Fuel purity assurance
  - Long-life compressors
  - Accurate dispensing/complete fills
  - System reliability
  - Safety through appropriate codes & standards and best practices
  - Capital outlay & return on investment

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Proposed Solution

- Develop and validate onsite, integrated natural gas-to-hydrogen fueling stations
  - Develop and/or test state-of-the-art subsystems
  - Address integration, operation, maintenance, reliability, and safety considerations
  - Pre-package systems that can be shipped onsite and quickly dispatched
- Leverage compact & efficient hydrogen generation technology
- 40 to 60 kg/day system with nominal 5000 psig dispensing

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Project Goals and Objectives

- Quantitative DOE Goals*:
  - Cost: high-pressure hydrogen at $3.00/kg or less by 2005 ($1.50/kg by 2010)
  - Fuel processing efficiency: 72% by 2005 (75% by 2010)
  - Fuel purification: 82% recovery by 2005 (90% by 2010)
  - Compression Energy: 85% by 2005 (88% by 2010)
- Qualitative Goals:
  - Minimize infrastructure investment cost and risk by leveraging existing energy infrastructure
  - Avoid high H_2 delivery costs and logistics problems by using onsite production
  - Provide technology transfer to a spectrum of industry participants and stakeholders

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* From Table 3.1.2, ***Hydrogen, Fuel Cells & Infrastructure Technologies Program: Multi-Year RD&D Plan***

Program Participants

- Gas Technology Institute
  - Program manager, fuel processing subsystem producer, system integrator
- Working with & evaluating range of potential technologies
  - Existing players
    - FuelMaker Corporation, ANGI International, GreenField, Norris Cylinder Co., CPI Industries, General Dynamics/Lincoln, Dynetek, Emerson Process Controls, OPW, others
  - New entrants
    - Several potential technology and subsystem suppliers for compressors, dispensers, fuel purification

Leverage substantial CNG experience base

Explore new solutions and companies

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Project Plan Overview

Program Duration 02/02 – 02/05	Phase I Design	Phase II Development/ Lab Test	Phase III Field Test/Dev.
	2/02-9/02	9/02–2/04	3/04–2/05
Fuel Reforming	**8/2002**	**2/2004**	
Fast Fill Testing	**8/2002**	**2/2003**	
Dispenser	**8/2002**	2/2004*	7/2004
Compressor	**8/2002**	2/2004*	2/2005
Purification	**8/2002**	2/2004*	2/2005
Design/ Economics	**8/2002**	2/2004*	2/2005

- Phase I completed
- Fuel reforming task completed
- Fast-Fill characterization completed
- Phase II development in process with delays due to technical and budget factors

Bold and underlined items are completed.

* These task and timing being reschedule due to technical and program funding issues.

Plan & Approach at a Glance

Complete

> Task 1: Fuel Reforming
- Increase efficiency
- Improve turndown
- Controls

Complete

> Task 2: Fast-Fill Testing
- Build SOA Test Facility
- Refine CHARGE thermodynamic model
- Conduct testing

50% Complete

> Task 3: H2 Dispenser
- Validate filling algorithm
- Component availability & cost
- Metering and fill accuracy
- Code & safety issues

40% Complete

> Task 4: H2 Compressor
- Analytical design
- Tribology & materials
- Empirical testing
- Reformer/purifier interface

30% Complete

> Task 5: H2 Purification
- Adsorbent, membrane strategies
- Reformer/compressor interface

80% Complete

> Task 6: Design & Economics
- System design, model, and safety
- System controls
- Economic model

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Safety Considerations

- GTI has extensive H_2 and high-pressure gas experience
  - Specialized engineers & technicians
  - Use best practices for high-pressure lines and fittings
  - Real-time gas monitoring & safety systems
  - Active in codes and standards development

Accomplishments

- Comprehensive subsystem and integrated system design report completed
- Compact fuel processor designed, built, and tested (alpha)
- 2nd generation (beta) fuel processor subsystem built and tested
  - Includes all water treatment and natural gas/sulfur clean-up
  - Fuel processor efficiency exceeds DOE 2005 target
- Full-scale high-pressure hydrogen test facility constructed
- Thermodynamic hydrogen cylinder filling model developed (CHARGEH2)
- Comprehensive set of hydrogen fast-fill tests completed
- H2 dispenser algorithm developed and validated
  - Patent application filed; licensing plans in place
  - Various papers presented

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Accomplishments (cont.)

- Primary (100 psig) hydrogen compressor designed and built
- Secondary compressors (up to 7000 psig) undergoing materials evaluation and life testing
- Pressure Swing Adsorption (PSA) test facility constructed
- PSA tests underway
  - Testing new compact PSA unit as part of a confidential program
- Integrated System Engineering and Construction
  - Steel skid procured and prepped
  - Fuel processor installed
  - Natural gas & water treatment systems installed
  - System controls procured and programming initiated
- Comprehensive system economic model developed
  - Various papers presented
  - Conducted additional analyses for DOE to evaluate size effects

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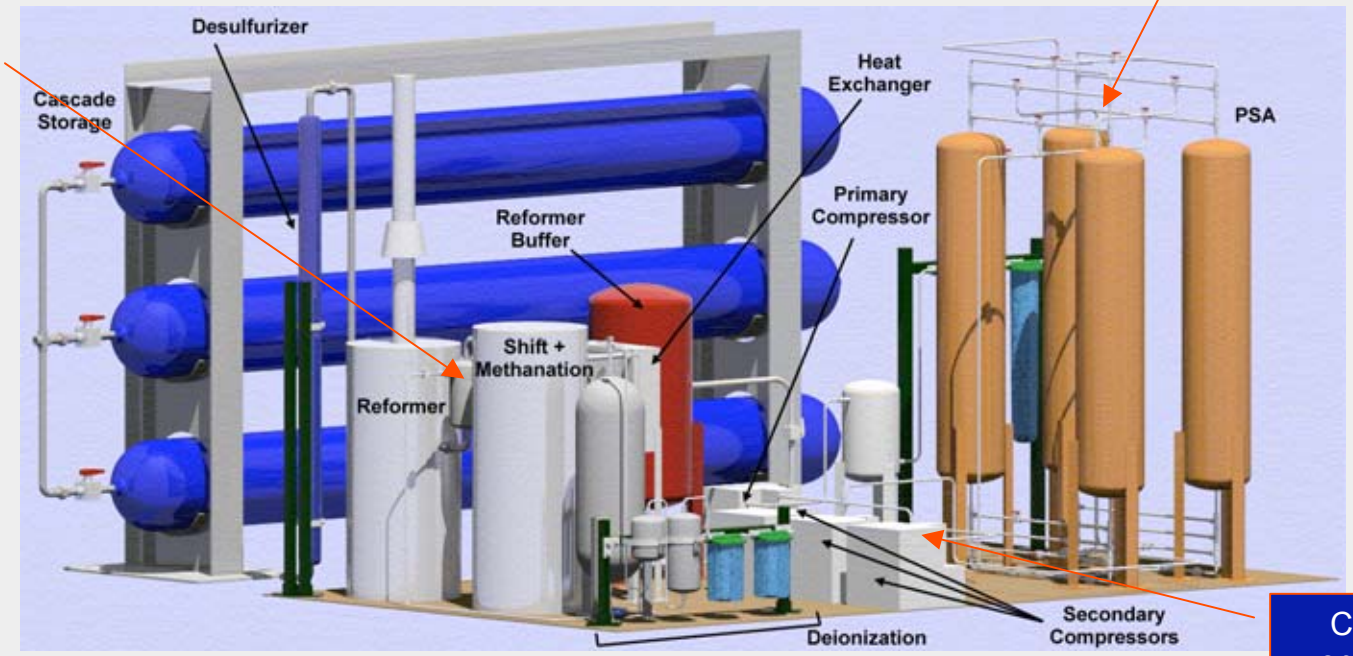
Preliminary Natural Gas to H2 Fueling Station Design

Evaluate more compact, simpler, lower cost PSA option

Testing new catalysts to boost output by 20% or more

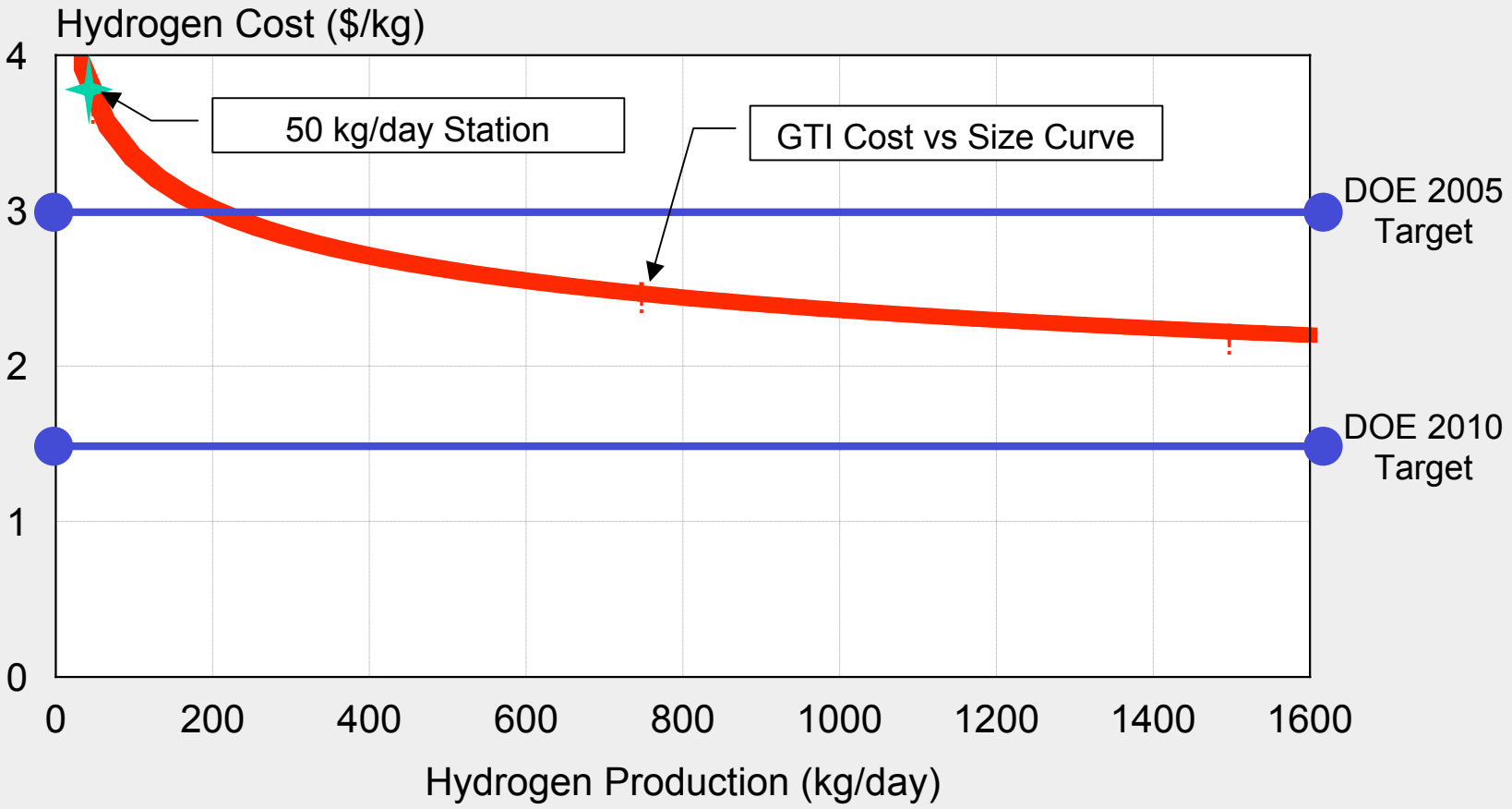


Consider options for gas compression

Further refinements underway to reduce size & cost

Hydrogen Fuel Station Costs

Capital, Operating, and Maintenance
Natural Gas Reforming



Source: Gas Technology Institute
Natural gas cost = $4.75/mcf

GTI Compact Fuel Processors

50-80 kg/day
H_2 Generator

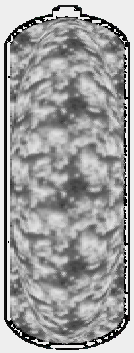
H2 Generator
Controls

Complete 50 kg/day fuel processor developed

Equipment rated to comply with fire safety codes

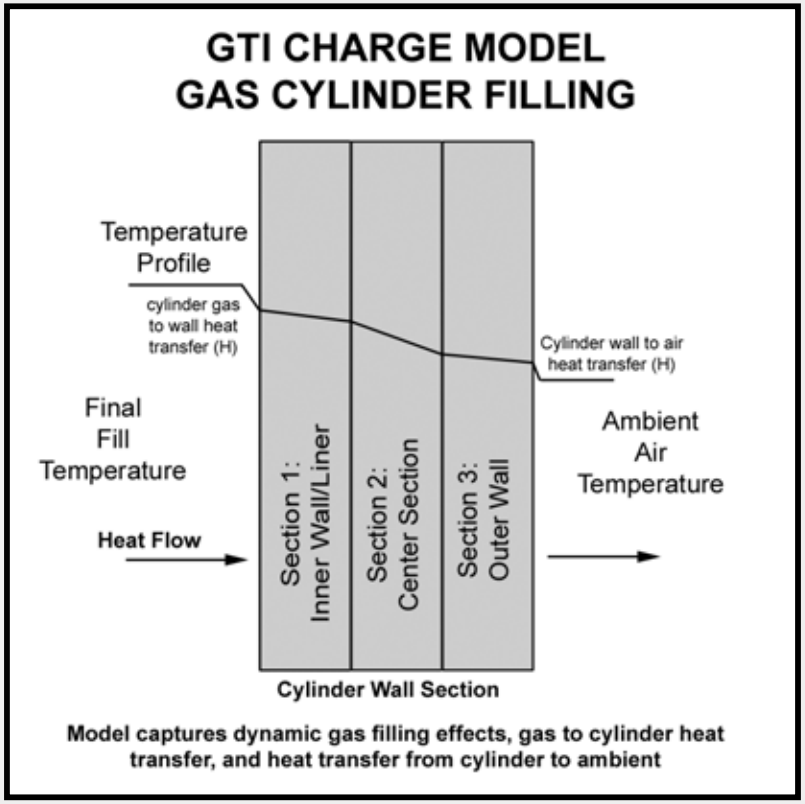
Four-Step Hydrogen AccuFill Development Process

Model	Test	Correlate	Implement
Develop first-principle thermo-dynamic model	Empirical testing under varied conditions	Regression analysis using first-principle model	Code development and dispenser integration



GTI CHARGE H2 Model

- First principle model of dynamic fast-fill process with real gas properties
  - Uses multiple differential equations
  - Filling of cylinders
  - Discharge of ground storage
- Assess cylinders of different size & construction
- Various starting & ending conditions



H_2 Cylinder Filling & H_2 Dispenser Validation

Simulated hydrogen dispenser

1

2

1. Accurate mass flow meter, cascade controls, and instrumentation
2. High-pressure hydrogen three-bank storage cascade in temperature-controlled environmental chamber
3. Ultra-high-precision, intrinsically safe scale for high-pressure H_2 cylinder gravimetric fill ratio validation and meter accuracy testing

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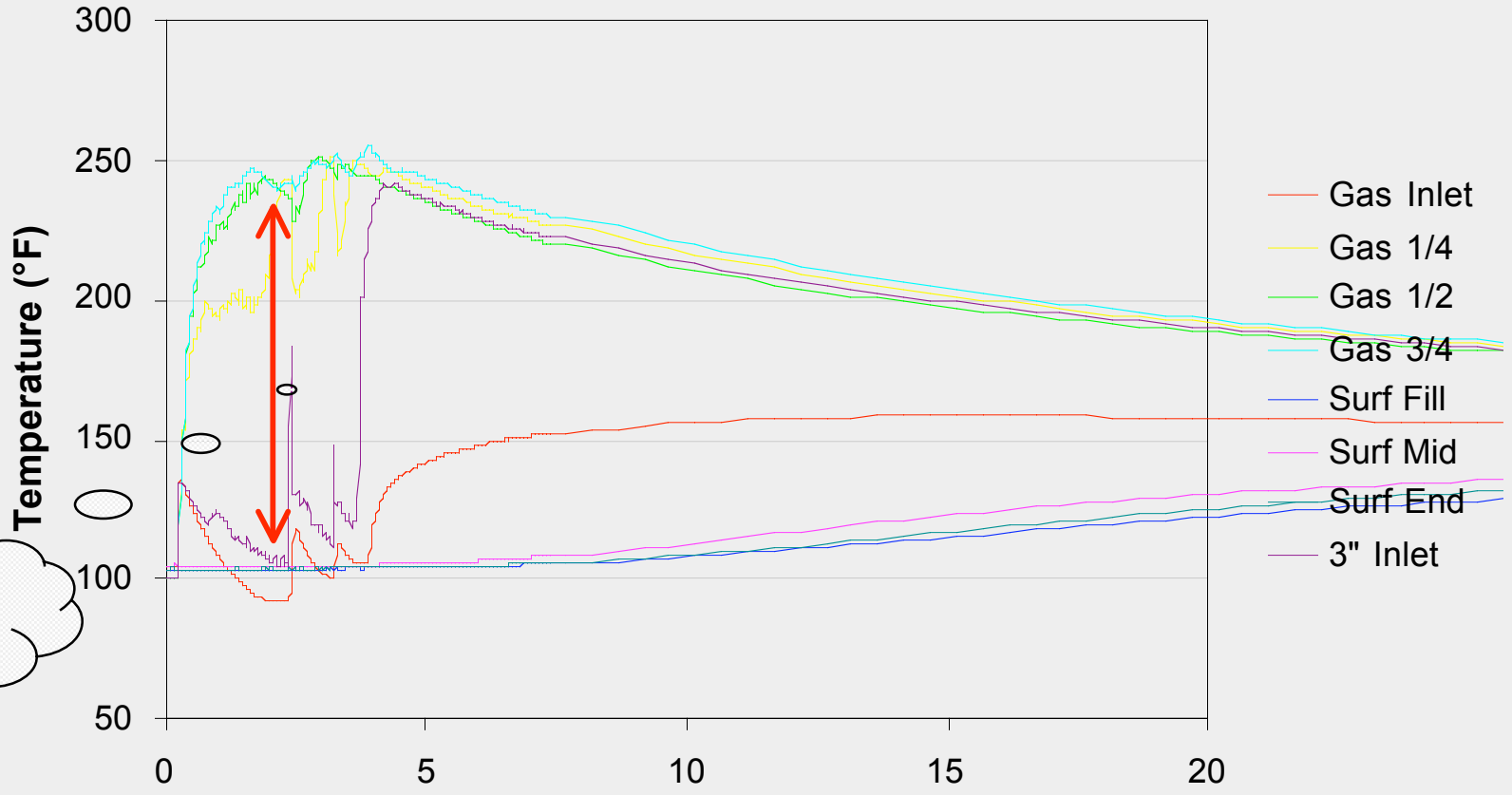
Hydrogen Cylinder Filling

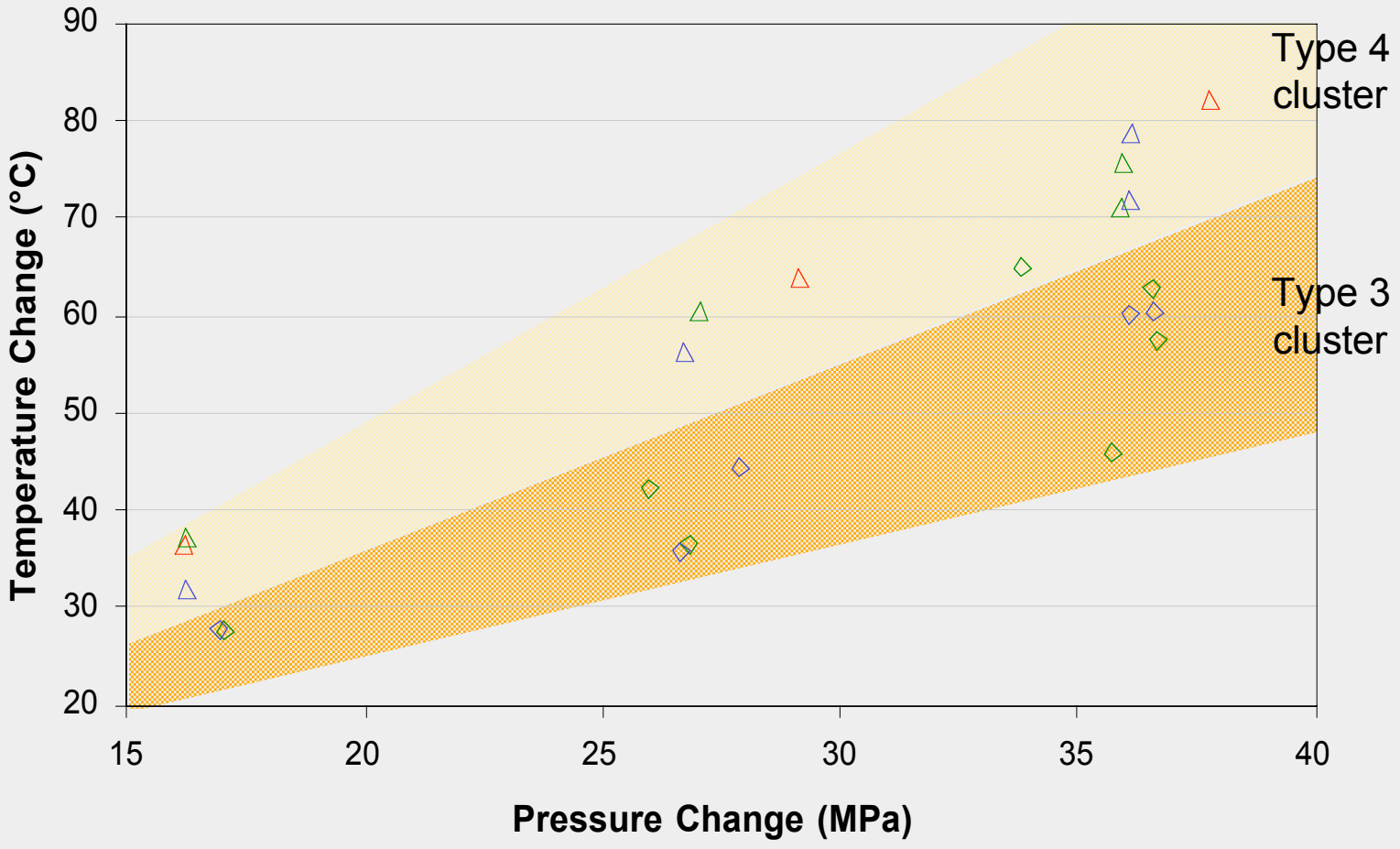
- Highly dynamic process with temporal and spatial temperature dependencies



Correct temperature?

Type 4 cylinder, 105°F, under 4 minutes

Hydrogen AccuFill Test Scatter plot



Hydrogen AccuFill Validation Testing

- Completing test and validation phases
  - Developed code, defined hardware and interface elements
- Over 44 cylinder filling tests
  - Variety of initial pressures and temperatures
  - Single and combinations of cylinders

Group	Avg. Fill %	_	n
All	100.5	2.68	44
> -20°C	99.6	2.19	32
Type 3 > -20°C	100.8	1.38	20
Type 4 > -20°C	96.9	1.26	7

Interactions and Collaborations

Gas Technology Institute

- Founding Member - National Hydrogen Association
- Member - U.S. Fuel Cell Council
- DOE Executive Advisory Council for FreedomCAR
- Secretary - SAE Fuel Cell Standards Committee
- International Code Council Ad Hoc Hydrogen Committee
- International Energy Agency Advanced Motor Fuels Annex
- U.S. TAG to ISO/TC 197 (ISO/CD 15869) and ANSI/NGV2 on hydrogen vehicle cylinder standards
- Technology exchange with numerous companies and organizations in U.S., Canada, Japan, China, India, and Europe
- **Present on this work at various meetings:**
  - World Hydrogen Energy Conference (6/04), NHA Annual Meeting (04/04), others

FuelMaker Corporation

- NFPA committee on hydrogen fueling system fire safety codes

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Next Steps

- Complete build-up and testing
  - Initially, fuel processor, primary compressor, and PSA system
  - Secondly, high pressure compressor, storage, dispenser
  - Fine tune system integration and controls
- Target full system test by 1Q/2005
- Work with partners on field testing and filling hydrogen fuel cell vehicles
  - Ongoing discussions with City of Chicago
- Work with potential partners on additional systems
  - Several possible projects being evaluated for follow-on development and demonstration

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Conclusions

- Efficient, compact fuel processing feasible
  - 75 to 80% efficiency is practical; up to 85% possible
- Complete fill hydrogen dispenser algorithm developed and validated
  - Simple approach that avoids added cost, complexity
  - Technology transfer through license
  - Additional standards development needed
- Fuel clean-up systems
  - Improved PSA packaging solutions needed
  - Membrane technology advances desired
- Onsite hydrogen stations feasible
  - More cost savings needed over coming years

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